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Embedding sustainability to produce an award winning chemical engineering programme: some challenges and learnings

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Abstract

Since writing about the 'the need to embed sustainability' into chemical engineering programmes in a 2009 paper (Byrne & Fitzpatrick, 2009), the authors have endeavoured to walk the walk by helping embed sustainability into the Process & Chemical Engineering undergraduate degree programme at University College Cork. This has been achieved both through the development of 'primary' bespoke modules with explicit sustainability related foci, as well as through the development of a coherent sustainability related context right throughout the programme, and across modules more generally. Nearly a decade on, this approach yielded international recognition, with a successful submission by the authors on behalf of their programme, which resulted in the award of the 2016 Teaching Sustainability Award by the Institution of Chemical Engineers (IChemE), an award given with the purpose of *'encouraging the development of better approaches to integrating sustainability principles and values into undergraduate teaching'* among IChemE accredited programmes globally.

This paper provides a reflective account of the evolution (in thinking and practice) made to the Process & Chemical Engineering degree at University College Cork over the past number of years on its sustainability journey, from the perspective of the authors who have championed this journey, and demonstrates how a confluences of various environmental factors, operating at various levels, can help facilitate iterative change and development.

1 Introduction

"Dedicated modules and elective streams alone are not in themselves sufficient to demonstrate how sustainability should be the context through which 21st Century chemical engineering must be practiced. To do this programmes must inherently and consistently demonstrate the need for sustainable practice."

The above citation, taken from a paper entitled 'Chemical engineering in an unsustainable world; obligations and opportunities', in the IChemE journal *Education for Chemical Engineers*, (Byrne & Fitzpatrick, 2009) represented both an expression of belief and a statement of intent by the authors of this paper. Over the following decade, along with colleagues on the Process & Chemical Engineering degree at University College Cork, the authors have sought to develop a programme with sustainability as both core and the *context* through which process and chemical engineering is both taught and practiced. This is both in line with contemporary drivers within the discipline, for example, as articulated by the Institution of Chemical Engineers 2007 Roadmap for the profession through the 21st Century (IChemE, 2007), as indeed across other disciplines and within (higher) education more generally (UNESCO, 2015, 2017; Byrne et al., 2016). Research and associated publications around embedding sustainability into contemporary

engineering education has also been a focus of the authors in the intervening period (e.g. Byrne, 2012; Byrne et al., 2013; Byrne & Mullally, 2014; Byrne, 2014; Fitzpatrick et al., 2015; Fitzpatrick, 2016, Byrne & Mullally, 2016; Fitzpatrick, 2017).

2 The Journey

Both of the authors were educated on conventional chemical/engineering programmes in Ireland (both at University College Dublin) through the nineteen eighties and nineties. These programmes reflected engineering programmes across Europe at this time, with a limited amount of (emerging) environmental engineering content (typically included to complement safety aspects on the programme), which were incorporated to support 'core' topics. Both authors had a general interest in, and empathy with protecting the environment, but in line with their education, saw this as chiefly a matter from a professional and educational perspective as largely amounting to reducing pollution as far as is technically and economically practicable, while maintaining site emissions below safe and legal operating standards. Essentially, process and chemical engineers produced a range of great processes and products for society, so once we kept our bibs clean and operated within evolving legal environmental and safety standards, then all would be well.

Throughout the nineteen nineties and around the turn of the century, issues around climate change, while seen as being potentially problematic, and potentially impacting on chemical engineering (given that manufacturing and the process industries were responsible for carbon emissions), these were not understood to be much more problematic than say, issues around the hole in ozone layer (which was seen to be eminently fixable). At any rate, it was seen as an intergenerational issue that would be something that maybe our grandchildren might have to face up to.

However, a tipping point came for Edmond Byrne in the case of Al Gore's powerful Academy winning movie 'An Inconvenient Truth', which emanated from the book of the same name (Gore, 2006). The movie was being shown in a local arthouse cinema in Cork, and resonated profoundly with me, as it did with much of society more generally, since it exposed the sheer scale, immediacy and impact of climate change. Indeed, it precipitated a self-awakening by revealing the starkness of the situation, while highlighting the deeply ethical nature of this environmental issue, in a way that resonated deeply for me, both as a citizen and as an engineer and educator.

At this time, I was also teaching a first year introductory module on Process & Chemical Engineering, a sort of catch all introductory module which, among other things (e.g. material and energy balances, process control, introduction to unit operations), incorporated sections on environmental engineering and engineering ethics. Up to that point I considered environmental engineering as a sort of end of pipe activity which enabled process companies maintain their emissions levels within regulatory frameworks. Better still if new and innovative processes or solutions could be engineered to reduce or eliminate such waste. Meanwhile, I had considered teaching of engineering ethics to be a largely separate and orthogonal activity, which called upon personal integrity and moral standing and which might sometimes involve ethical dilemmas for individuals, up to and including potential considerations around whistleblowing. Engaging with the latter, in particular involved in-class ethical fictional case studies, where students might be asked to discuss, debate and identify optimal courses of action for unfortunate engineers, as has been the standard practice in much engineering ethics teaching (e.g. see Shallcross & Parkinson, 2006). This approach

however, always still left me feeling a bit cold and unfulfilled in my attempts to teach this topic; somehow engineering ethics must be more than just about students moralising about notional personal ethical dilemmas.

Gore's movie however resonated deeply with me. Not only did it open my eyes to the vast scale and urgent immediacy of climate change, it, perhaps more importantly, facilitated me in making a number of connections. First of all, that we as engineers, as key players in the construction of many of society's physical manifestations, processes and products, need to raise our heads up and consider our impact on society around us, rather than just concentrating on that which is going on inside the perimeter (system boundaries) of our plants. For what goes on respectively within and without the (open) system boundary of the plant are deeply and intrinsically connected. Thus the agonising micro-ethical personal moralistic dilemmas of individual engineers (as taught in the engineering ethics class) could only be (an incomplete) part of the picture; engineers also work in and contribute to broader societal workings, and thus we are both implicated and responsible for macro-ethical issues such as those around climate change, and can (and are ethically obliged) to contribute to addressing these (alongside others). As Gore put it in his corresponding book; *'Our capacity for analysis sometimes leads us to an arrogant illusion: that we are so special and unique that nature isn't connected to us. But the fact is, we're inextricably tied.'* (Gore, 2006). Indeed it became apparent to me that the connections were not just on the micro (individual) versus macro (societal level) ethical spectrum (operating iteratively as recursive drivers of societal cultural change and personal behaviour), but also that climate change was really just one manifestation of an unsustainable societal construct (along with biodiversity loss, environmental degradation of oceans, air and land, etc.) which are themselves deeply interconnected with societal issues around water, energy, food and material flows. Moreover, it soon became baldly apparent to me that the pillars of environmental engineering and engineering ethics were also closely linked, for as Gore put it as his academy speech *'we need to solve the climate crisis: It's not a political issue; it's a moral issue.'*

This movie moved me to the extent that I brought the whole first year class to watch the movie at the nearby cinema that was showing it in Cork as part of their engineering ethics class. Thereafter, stimulated and informed by contemporary work of researchers on engineering ethics such as Herkert (2005), Bucciarelli (2008) and Conlon (2010) my outlook on the role of engineering ethics evolved and broadened, to more deeply and explicitly incorporate the corresponding macro-ethical responsibilities of engineers to society and environment. This precipitated the development of a personal research interest and corresponding outputs in this area (e.g. Byrne, 2012; Byrne & Mullally, 2014) and thereby a recognition of the value and necessity of more explicitly transdisciplinary approaches in addressing emerging complex contemporary challenges (Byrne at al., 2016; Byrne & Mullally, 2016)). I was also undertaking an MA in Teaching and Learning in Higher Education at the time (graduating in 2008), which helped facilitate the development of a personal understanding of learning in terms of constructivist approaches, something which is alien to the traditional modernistic worldview as espoused by classical engineering education, but which is essential to effectively engaging with sustainability issues and associated narratives, including education for sustainable development (UNESCO, 2015, p. 15).

The second author of this paper, John Fitzpatrick, has been teaching chemical / process engineering students since 1995 in mainly technical subjects. Around 2003, he started teaching two half modules in environmental protection. These focused mainly on management and technical aspects from a process

industry perspective, including waste treatment & disposal, environmental legislation, waste minimisation, life cycle assessment, cleaner process technology and cleaner energy. Over time, he had the niggling feeling that the big challenges to moving humanity towards a sustainable paradigm lay in broader global societal challenges, such as climate change and the food-energy-water nexus. Furthermore, he developed the feeling that the economic and social domains have a major role to play and are possibly the "game-changers" (Fitzpatrick, 2017). This is not to say that the technological innovation and challenges are not important; yes they are but the critical levers to moving humanity towards a sustainable paradigm may exist in the economic and social domains. He also had the niggling feeling that he was complicit in producing 'technically competent barbarians' (see Barry, 2012, p.126), who were not truly fit-for-purpose for the sustainability challenges of the 21st century.

3 A Process of Directed Chance

As colleagues in a small tight knit department, and each with an active (research) interest in engineering education as well as broader issues of sustainability, both authors inevitably discussed how and to what extent sustainability related issues should be incorporated into the engineering curriculum. An opportunity arose to host an international conference on engineering education in 2010, the 3rd International Symposium for Engineering Education (Byrne, 2010), where the authors comprised the majority of academics on the local organising committee (including the conference Chair). A theme which reflected a particular interest of ours was selected, specifically on engineering education for sustainability/sustainable development. Thus the chosen conference theme was *'Educating engineers for a changing world – Leading transformation from an unsustainable global society'.* We worked hard to make this a successful conference which would attract academics interested in this area and incorporated, among other things, a delegate workshop on the theme of *'Accreditation and Sustainable Engineering.'* with a corresponding delegate primer paper which looked at state of the art regarding the sustainability requirements of engineering accreditation bodies globally (Byrne et al., 2010). Outputs from this workshop provided material for a subsequent paper published in the *International Journal of Sustainability in Higher Education* (Byrne et al., 2013). The symposium was very successful, attracting a number of like-minded academics among the 135 participants from 16 countries across all continents. Among them were some from the EESD conference series. It was this pioneering community that the UCC academics engaged with, were inspired by and learned from, from the 2010 conference in Gothenburg (Chalmers University of Technology) to the present series and beyond (the 11th EESD is scheduled for Cork in 2020).

This engagement led to discussions among the authors about the possibility of jointly developing a new core bespoke module on 'Sustainability in Process Engineering' (PE3011). Having discussed it with and received the support of colleagues and our local curriculum committee, the green light was given for this new module which began in Spring 2011. This module provided a focus for sustainability on the programme, and took a broad view of the topic at hand, not just covering socio-technical aspects such as life cycle analysis, but also making explicit the underlying values and paradigms around sustainability narratives and the nature of complex non deterministic systems; essentially aiming to develop the generic competencies, including integrative approaches and critical thinking skills necessary for and that correspond with education for sustainable development (ESD) more generally (Bourne & Neal, 2008; UN, 2012; Byrne, 2014).

Neither was our earlier call for *'the need to embed sustainability'* (Byrne & Fitzpatrick, 2009) forgotten, and other modules on the programme were, with the support of colleagues, developed to help deliver this aim. This is an important point; while colleagues were not perhaps as enthused or as interested in issues around EESD, they nevertheless were generally supportive of our endeavours, while also willing to incorporate sustainability elements and indeed contexts of sustainability into their respective modules and to engage with us, where appropriate, as they generally saw the greater value of this endeavour. Moreover, the macro environment as facilitated both by the likes of professional accreditation bodies such as the IChemE and Engineers Ireland, as espoused through their accreditation requirements and other drivers such as the IChemE Roadmap (IChemE, 2007) and their associated sustainability related prizes and initiatives, or Engineers Ireland Code of Ethics (Engineers Ireland, 2018) certainly provided useful top down professional body leadership and a broader context for facilitating and promoting this approach. Moreover, a positive sustainability ethos and leadership across our university also helped provide a positively oriented context.

Sustainability embeddedness was achieved through the programme via a number of modules at each stage; these included the obvious ones such as the first year module on *Professional Engineering Ethics* (see Byrne & Mullally, 2014) and the two *Safety and Environmental Protection* modules, but also, with support of colleagues on the programme, a sustainability ethos and applications found their way into other less obvious modules also, such as for example, *Introduction to Biochemical Engineering* and *Advanced Process Design* (Table 1). Perhaps the biggest achievement (and challenge) of all, was the evolution of the capstone final year design project from an initial point where 'sustainability' was treated as, at best an end of pipe add-on, to the point whereby sustainability thinking is an inherent part of the module as students are encouraged to integrate it, in particular at the early scoping and key decision making stages of the project. Moreover, students are also encouraged to view the broader societal context of their design, including the consideration of socio-economic aspects and frameworks, which in terms of eliciting transformative change, may be have a bigger and more fundamental role to play than the development of technological artefacts and processes (Fitzpatrick, 2017). However, while many of the big economic and social sustainability issues are at the macro-societal level, and thus may be considered too broad in scope for inclusion in the design project, students are nevertheless challenged to at least reflect on their sustainability education and exhorted to consider framing the boundaries of the broader social and economic environment from a sustainability perspective within the context of their respective designs. This approach can thus help students *'explicitly reflect on how they envisage the scope of their project and to what extent they might engage with and incorporate sustainability issues in a meaningful way which recognises how socio-economic and political factors interact with technical ones within the open system that the design problem is actually situated'*. (Fitzpatrick & Byrne, 2017).

To this end, both authors provide some guidance on the sustainability requirements of the group design project, in support of the module coordinator and academic delivery team. Moreover, the effective required output for the groups is a proposed entry into the IChemE's Macnab-Lacey final year sustainability design prize, which is a prize awarded annually by IChemE *'to the undergraduate student design project team whose design project submission best shows how chemical engineering practice can contribute to a more sustainable world'*, among other things in order to *'influence chemical engineering departments to position sustainable development at the heart of the curriculum'* (IChemE, 2018). One entry is allowed per third level institution, so our academic design team confer to choose a UCC entry each year.

Table 1 Modules designed to embed sustainability on UCC's programme

'Primary' Sustainability Modules	*'Secondary' Sustainability Modules*
PE1006 Professional Engineering Communication & Ethics **Objective:** develop appreciation of professional ethics through application in complex problems and case studies. **Learning Outcome:** Relate professional engineering practice to the ethics and ethos of the profession and the role of engineering in society. Understand the nature of complex wicked problems and apply appropriate strategies for resolving such problems.	**PE1003 Intro. to Process & Chemical Engineering** **Objective:** understand the role and responsibilities of chemical process engineers. ..selecting process alternatives, constructing process diagrams, performing mass and energy balances. **Learning Outcome:** Discuss the role of process engineering with respect to production efficiency, safety and the environment.
	PE2005 Introduction to Biochemical Engineering **Learning Outcome:** Apply an engineering approach to ..development of sustainable industrial biochemical systems. **PE2011 Plant Design and Commissioning** **Learning Outcome:** Appraise the design and operation of process facilities with specific reference to sustainability, plant safety and plant management.
PE3011 Sustainability in Process Engineering **Objective:** Examine concepts, constructs, models and values relating to sustainability and sustainable development. Examine relationships between complex systems, thermodynamics and sustainability and how these relate to post-normal engineering roles, responsibilities and practice. examine environmental management systems and clean/green concepts & technologies and how they can be applied to sustainably produced products from process industries. **PE3008 Safety & Environmental Protection I** **Content:** Environmental protection: Human impact on the environment; Ecological limits; Water and waste water treatment; Hazardous waste treatment/disposal; Air pollution control.	**PE3001 Applied Thermodynamics and Fluid Mechanics** **Learning Outcome:** Employ a whole system design approach to optimise pump-pipeline system design.
PE4004 Safety & Environmental Protection II **Objective:** Understanding of Process Safety and Environmental Protection/Sustainability. **Content:** Legislation; Solid waste treatment and energy from waste plants. Cleaner process technology and cleaner energy in the process industries. Corporate environmental sustainability. Ecological economics. **PE4006 Design Project** **Learning Outcome:** Design a process with a sustainability perspective	**PE4001 Advanced Process Design** **Objective:** developing, designing and scaling up innovative, sustainable and creative chemical engineering products and processes. **Learning Outcome:** Assess the opportunity for green engineering and sustainable chemical product design

Apart from engaging with the broader EESD community on a European and global stage, as well as with chemical engineering academics in our own institution, we have also engaged over this period to a far greater extent in our local university with colleagues of like mind right across the disciplines. ESD competencies naturally call for inter and transdisciplinary engagement, something which can be far easier to recognise than enact. However, this was assisted by an environment at UCC which encouraged environmental engagement right across the university (University College Cork was the first university in the world to receive the Green Flag for environmental friendliness (2010) and reached a high point of overall number two in the global UI Green Metric Universities rankings list in 2014 (Byrne et al., 2016a)), guided by the pioneering leadership of current Registrar and Deputy President (and Professor of Zoology)

John O'Halloran, alongside a cohort of like-minded and committed staff and academics. In this context, Ed Byrne reached out to a lecturer in Sociology, Dr Ger Mullally, and forged a relationship which facilitated the development of a transdisciplinary group sustainability assignment on the third year *Sustainability in Process Engineering* module, by also incorporating the assignment on a third year *Sociology of the Environment* module. Thus undergraduate engineers were brought into collaborative contact with sociology and government students. After all, there's hardly any point in us exhorting our graduates to go out and work with other disciplines in the workforce for good, if we are not prepared to *walk the walk* and prepare them for that within the confines of the uni-versity! This journey also led to coming into contact with other like-minded colleagues, such as the food geographer Dr Colin Sage, who instigated the UCC supported transdisciplinary Environmental Citizenship Research Priority Area ('Sustainability in Society') in 2011 (Mullally et al., 2016), which sought to (re)consider sustainability in a way which both draws from disciplinary contexts and knowledge but also transcends and builds on new contexts.

Disciplinary imperatives were also tended to across the programme. The sustainability ethos of the programme was developed and refined, drawing on research from Imperial College, London which showed that the desire to *'make a difference to the world'* (Alpay et al., 2008) in their careers was a key driver in enthusiastic idealistic young school leavers (in many cases ahead of making money, designing new things and travelling), in particular among females. This too was our experience; students generally were overwhelming positive about both the ethos and the respective modules around the programme, indeed even, and especially some of the more novel aspects, such as working with sociology students on a sustainability assignment. For example, the following represents (anonymously collected) feedback from a number of Process & Chemical Engineering students on their experience of this assignment as part of the Sustainability in Process Engineering module:

- *'Completing an interdisciplinary [assignment] gave me a more all round view on sustainability as it made us look at sustainability from more than just an engineering point of view.'*
- *'A major learning point of this was taking on board alternative perspectives of problems, outside of engineering solutions.'*
- *'[The] transdisciplinary approach was enlightening – an engineering solution isn't always the only option.'*
- *'Greater understanding and appreciation of perspectives [from those] which don't work on "hard science"'*
- *'Working in a team with vastly different opinions is hugely valuable to our careers in the future.'*

The positive feedback from our students, allied to the aforementioned research on the attraction of making a positive difference, encouraged us to explore the value of using the broader sustainability ethos of the programme as a soft marketing tool to attract potential students to the programme. Inspired by the IChemE's visionary 2007 'Roadmap', a strategic plan for the profession for the century ahead, and its associated cover image (IChemE, 2007), Ed Byrne worked with colleagues to develop a forward looking 'journey ahead' image which seeks to convey both the essence of the UCC programme (and the profession), while also highlighting the role and opportunity that chemical engineers have in both facilitating and helping to lead transformational societal change (alongside others) when practiced through a sustainability lens (Figure 1).

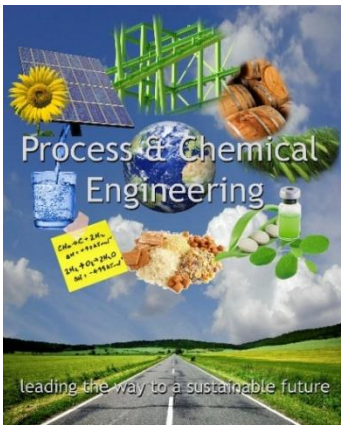

Figure 1 UCC BE Process & Chemical Engineering promotional collage

4 International recognition; A Staging post

In 2015, the Institution of Chemical Engineers instigated a Sustainability Teaching Award, organised and promoted by the Sustainability Interest Group in conjunction with its Education Interest Group. It was developed in order to encourage *'the development of better approaches to integrating sustainability principles and values into undergraduate teaching'*. The authors of this paper decided to submit an entry to this award on behalf of the UCC Process & Chemical Engineering programme for the second iteration of the award in 2016. To our delight our entry was deemed the winner on the first attempt, beating off highly commended competition from top universities across the globe, with the judging panel noting that they *'were particularly impressed by your integration of sustainability teaching across the curriculum, with good examples of interdisciplinary projects and varied assessment with student comments indicating their appreciation of the approach.'* (UCC, 2017). In making the award, the IChemE also noted that *"University College Cork demonstrated that they could integrate sustainability teaching principles across the curriculum, which will provide their chemical engineering students with a set of values to apply to their future careers."* (IChemE, 2017). The award was presented at the IChemE's AGM in Birmingham, England in May 2017 by the incoming IChemE President John McGagh. In presenting our case for the award, we highlighted a number of modules from across the programme, which we indicatively labelled 'primary' and 'secondary' modules, with respect to the degree to which they aim to embed sustainability across the four years of the degree programme (see Table 1). The secondary modules highlighted are indicative; others modules also incorporate a sustainability ethic.

5 Conclusion and Learnings

We have found the journey to be both fascinating and rewarding as we've sought to help transition our programme from a more traditional one, whereby sustainability is envisaged in a narrow way, that is, concerned with simply boosting efficiencies and improving environmental emissions, to one whereby it explicitly seeks to add value (and values) to contemporary chemical engineering education, through recognising that *'the key ingredient required ..is an aspiration to enable and empower learners to meet their full potential by developing the necessary skills and aptitudes (critical, reflective and complex thinking, self-awareness and empathy, teamwork, listening and communication skills) to be fit-for-purpose'* (Byrne, 2014) contemporary chemical engineers. Indeed, as we've attempted to push various doors (via our students, colleagues, accreditation bodies, industry, peers), we have found that not only have they generally swung open with surprising ease, but that they've often opened altogether new and exciting vistas. We offer this account as one which can hopefully help and inspire others on similar pathways, while also offering a perspective on what and how we see as 'core' chemical engineering, to educate fit- for-purpose graduates in addressing contemporary and emergent 21st century challenges, in a way that can contribute meaningfully towards authentic societal sustainability and human flourishing.

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